TR-22

TECHNICAL REPORT

# LOCAL ENVIRONMENTAL FACTORS AFFECTING ICE FORMATION IN SONDRE STROMFJORD, GREENLAND



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## FOREWORD

Successful Arctic operations require a considerable amount of preparation and planning. To aid such planning, the Hydrographic Office has been engaged in the development of various techniques for the forecasting of the formation, growth, movement, and disintegration of sea ice, especially in the harbor areas, since each Arctic and subarctic harbor constitutes a special environmental problem.

This report presents a study of the environmental factors that are peculiar to Søndre Strømfjord and evaluates their effect on the formation and growth of sea ice in the harbor area. The ice growth in the autumn of 1953 was studied in detail.

The conclusions expressed in this report are tentative and may require revision as more data become available. All additional information which might amplify or modify this report will be welcomed by the Hydrographic Office.

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# I. INTRODUCTION

Søndre Strømfjord is located on the southwest coast of Greenland, oriented in a general southwest-northeast direction. A chart of the fjord is shown in figure 1. The entrance from Davis Strait is at approximately 66°N 53.5°W, and the head of the fjord is near 67°N 51°W. The sides of the glacier-made canyon rise abruptly to a height varying from 1,000 to nearly 4,000 feet along the entire narrow channel.

The fjord is typical except that its length is somewhat greater than most of the fjords along the coast of Greenland. Several glaciers debouch directly into the fjord, while others empty into rivers which bring a large volume of fresh water into the fjord during the summer melting season. Of these rivers the largest is Watson River, the mouth of which forms the head of North Fork. The glaciers which provide the fresh water of the fjord are all part of the main Greenland Icecap with the lone exception of Sukkertoppen Isflade which is a separate entity.

# II. OCEANOGRAPHY AND CLIMATOLOGY OF SØNDRE STRØMFJORD

## A. Oceanography

1. Bathymetry. The depth of the fjord varies greatly, averaging 70 fathoms at the entrance near Cruncher Island and decreasing northeastward to only 12 fathoms near the reef. The middle of the channel is then quite shallow (10 to 20 fathoms) because of the deposition of moraines by the glaciers of Sukkertoppen Isflade. Near Sarfartok Point a depth of 150 fathoms occurs very abruptly. This depth continues to the mouth of Bowdoin Bay, with depth of North Fork being a little less than 100 fathoms.

The bathymetry of North Fork is characterised by a sudden drop along the south shore while the north shore slopes gradually. A 5-fathom contour may be drawn from Point Brennan on the north shore to near the tips of the peninsulas that form Michigan Bay and then near the mouth of Watson River. The 50-fathom contour lies near both coasts at the entrance to North Fork, breaking away abruptly from Point Brennan and the Northwest Point of Nakajanga Peninsula. (Northwest Point is used hereafter throughout the text and on the charts, chosen arbitrarily as no known name exists.) The silt deposit from the mouth of Watson River forms a very gradual decline to the 50-fathom line in that area.

2. Currents. The observed surface currents in Søndre Strømfjord were clockwise, causing the ice fragments to move seaward along the south side of the fjord. Actually, the tides are more prominent than the currents.

3. Salinity. The salinity of the fjord averages 19.48°/oo at the surface in Michigan Bay and 20.2°/oo in the center of North Fork, as compared to 31 and 34 °/oo in the West Greenland Current near shore. Table I shows salinity samples taken during the period of this study. The first values show salinity fluctuations from day to day. However,

Table I - Salinity

| Sample No. | Salinity °/oo | Date | Time (Z) | Depth (Feet) | Air Temp. (°F.) | Water Temp. (°F.) | Ice Type or Thickness (inches) |
|---|---|---|---|---|---|---|---|
| | | | Station 1 (Dock at Camp Lloyd) | | | | |
| 1 | 10.0 | 9 Nov. | 1300 | Surface | 11.0 | 30.0 | None |
| 9 | 13.2 | 11 " | 1515 | " | 09.0 | 29.5 | Film |
| 10 | 19.2 | 12 " | 1400 | " | 00.0 | 29.7 | Slush |
| 11 | 21.3 | 15 " | 1400 | " | 03.5 | 30.0 | Slush |
| 12 | 16.7 | 16 " | 1715 | " | 05.0 | 29.7 | 2 Slush, Brash |
| 14 | 20.9 | 17 " | 1330 | " | 11.0 | 30.0 | ½ Slush |
| 15 | 16.6 | 18 " | 1830 | " | 28.0 | 30.0 | Thin Slush |
| 16 | 19.3 | 19 " | 1300 | " | 22.0 | 30.0 | None |
| 22 | 21.4 | 20 " | 1315 | " | 16.0 | 30.0 | Slush |
| 23 | 21.2 | 21 " | 1305 | " | 18.0 | 30.0 | Slush |
| 25 | 21.8 | 22 " | 1450 | " | 10.0 | 31.0 | Grease |
| 27 | 19.5 | 23 " | 1300 | " | -01.0 | 29.7 | 3/4 |
| 30 | 21.4 | 23 " | 1815 | " | 00.0 | 30.0 | 1 |
| 32 | 17.9 | 24 " | 1320 | " | 02.5 | 30.0 | Skin |
| 4 | 20.9 | 24 " | 1710 | " | 01.5 | 30.0 | Skin |
| 33 | 14.4 | 25 " | 1345 | " | 07.0 | 30.0 | Skin |
| 34 | 17.4 | 26 " | 1340 | " | 12.0 | 30.0 | Slush |
| 35 | 21.9 | 27 " | 1340 | " | 30.0 | 30.0 | 3 Snow Slush |
| 36 | 21.7 | 27 " | 1645 | " | 31.0 | 30.0 | 3 Snow Slush |
| 37 | 21.7 | 28 " | 1400 | " | 33.0 | 30.0 | Skin |
| 38 | 21.9 | 28 " | 1715 | " | 31.0 | 30.0 | Slush |
| 39 | 20.2 | 29 " | 1415 | " | 22.0 | 30.0 | Snow Slush |
| 40 | 22.1 | 2 Dec. | 1345 | " | 14.5 | 30.0 | Slush |
| 41 | 21.4 | 2 " | 1705 | " | 15.0 | 30.0 | Slush |
| 42 | 22.4 | 4 " | 1327 | " | 10.0 | 30.0 | Slush |
| 43 | 22.1 | 6 " | 1600 | " | 04.0 | 30.0 | Skin |
| 44 | 22.0 | 9 " | 1415 | " | -05.0 | 30.0 | Skin |
| | | | Station 2 - (66°57'N 50°57'W) | | | | |
| 2 | 20.3 | 9 Nov. | 1830 | Surface | 13.5 | 30.0 | None |
| 6 | 16.0 | 10 " | 1805 | 5 | 05.0 | 32.5 | Grease |
| 7 | 10.7 | 10 " | 1805 | 10 | — | 33.5 | - |
| 8 | 9.9 | 10 " | 1805 | 25 | — | 33.7 | - |
| 13 | 12.8 | 16 " | 1830 | Surface | 09.0 | 30.0 | Frasil, Grease |
| 17 | 20.0 | 19 " | 1345 | " | 23.0 | 30.0 | None |
| 18 | 20.3 | 19 " | 1727 | " | 20.0 | 30.5 | - |
| 19 | 21.3 | 19 " | 1727 | 10 | — | 33.0 | - |
| 20 | 21.6 | 19 " | 1727 | 30 | — | 33.0 | - |
| 21 | 21.8 | 19 " | 1727 | 75 | — | 35.0 | - |
| | | | Station 3 (North Shore Cove, West of Michigan Bay) | | | | |
| 24 | 21.3 | 21 Nov. | 1345 | Surface | 17.0 | 30.0 | Slush |
| 26 | 13.0 | 22 " | 1400 | " | 12.0 | 30.5 | None |
| 28 | 16.1 | 23 " | 1345 | " | -01.0 | 30.0 | Thin Film |
| 29 | 14.3 | 23 " | 1750 | " | 02.0 | 30.0 | ½ Film |
| 31 | 11.6 | 24 " | 1255 | " | 04.5 | 29.5 | Skin |
| 5 | 19.5 | 24 " | 1650 | " | 04.5 | 30.0 | Rubber |
| | | | Other Observations | | | | |
| 45 | 10.0 | 16 Nov. | 1830 | (Sample, 2" thick ice at Station 2) | | | |
| 46 | 17.2 | 2 Dec. | 1400 | (Sample, 8" core at center Michigan Bay) | | | |
| 47 | 15.7 | 6 " | 1600 | (Sample, 3" core at center Michigan Bay) | | | |

freezing weather stops the fresh water runoff from the glaciers and the ice cap. As mixing continues between fjord waters and the more saline waters of Davis Strait, the salinity of the fjord waters rises with progressively less fluctuation and levels off at nearly 22 °/oo.

4. Tides. The tidal range is slightly less than 11 feet. Calculations can be performed by figuring spring and neap tides at the head of the fjord to be 5 minutes later than at Argentia, Newfoundland. The tide at the entrance is 1 hour and 25 minutes earlier than at Argentia; there is a lag of 1 hour and 30 minutes between the entrance and the head of the fjord.

## B. Meteorology

1. Air Temperatures. An extreme maximum temperature of approximately 50° F. has occurred every month of the year, although the average maximum during the winter months is 12° F. Freezing temperatures have been recorded every month except August during the time of the climatological record. A summary of approximately a 10-year period of monthly minimum and maximum temperatures is given in table II.

Table II. Monthly temperature (°F.) maximums and minimums over approximately a 10-year period.

| Month | Extreme Maximum | Average Maximum | Average Minimum | Extreme Minimum |
|---|---|---|---|---|
| Jan. | 59 | 12 | -5 | -43 |
| Feb. | 50 | 10 | -7 | -40 |
| Mar. | 48 | 12 | -6 | -36 |
| Apr. | 54 | 24 | 8 | -16 |
| May | 67 | 46 | 30 | 6 |
| June | 73 | 58 | 40 | 28 |
| July | 71 | 59 | 41 | 32 |
| Aug. | 70 | 55 | 39 | 34 |
| Sept. | 66 | 45 | 32 | 10 |
| Oct. | 59 | 30 | 17 | -4 |
| Nov. | 59 | 23 | 9 | -34 |
| Dec. | 47 | 12 | 3 | -30 |

2. Cloudiness. The average annual cloud cover is 6 tenths. August, the cloudiest month, averages 7 tenths cloud cover while February and March have the least cloudiness with 5 tenths. The autumn months of October, November, and December have a mean cloudiness of 7, 6, and 6 tenths, respectively.

3. Precipitation. Precipitation is light in the fjord, averaging less than 1 inch in all months. Snow has fallen during every month except July. Snowfall averages 29 inches per year. During October, November, and December, there is a measurable snow cover on the ground for 18, 26, and 31 days, respectively.

4. Winds. The prevailing wind is from east-northeast, averaging 10 miles per hour and bringing cool dry air directly off the Greenland Icecap. This downdraft, though considerably compressed, is the coldest, driest air to reach the station. Wind speeds over 24 miles per hour occur 2.5 percent of the time.

## III. ICE GROWTH IN SØNDRE STRØMFJORD

### A. Observed Growth in Autumn 1953

The ice of North Fork was first observed on 7 November. Ice had formed initially on 3 November when a thin layer was observed in Michigan Bay after an accumulation of 232.5 degree-days of frost (°F.). This ice had reached a thickness of 3 inches by 7 November when it commenced to move out. Figure 2 shows the patch of ice, which had been inshore, now located offshore in waters with depths of 20 to 40 fathoms. It is known from calculations of the heat capacity of ice (Lee and Simpson, 1954) that the reservoir of heat in deeper waters usually prevents ice formation until after ice has formed in shallower waters. Circumstances indicate that tidal action has dislodged the ice and is moving it southwestward down the fjord. The average temperature was -4.6° F. on 6 November, and 12.5° F. on 7 November, with a maximum of 18° F. occurring at 1830Z on the 7th of the month. The wind averaged east-northeast at 8-10 miles per hour. The only explanation offered for ice breakup during this period is the high tide. Spring tides occurred on 7 November. The ice between Camp Lloyd anchorage and the dock area was continually being broken by a tug and her barges, no doubt facilitating any outward movement of the ice and greatly hindering ice growth.

The fjord remained ice free except for grease ice and thin ice in the shallows and shoals through 11 November. On 12 November shorefast ice again formed, reaching three-fourths of an inch in thickness (fig. 3). The small patches of floating ice were produced by tidal action.

The shorefast ice continued to grow until 17 November. Conditions from 13 to 15 November are shown in figure 4 for North Fork and figure 5 for the entire fjord. On figure 5, the ice between Sarfartok Point and second Moraine Point is the remnant of the first ice that formed on

3 November. This ice has moved more than halfway down the fjord in the 11-day interval. The location of the ice on the southeast side of the fjord indicates a surface current flowing out of the fjord, so that the circulation in the fjord may be clockwise, with surface water moving in on the north side of the fjord and out on the south side. Figure 5 also shows patches of ice in the northeastern part of the fjord, evidently composed of ice that formed near the mouth of Watson River where the water is shallow and the low salinity raises the freezing point of the water. As this ice is broken off by tidal action it moves with the current along the southern side of the fjord where it slowly breaks up and disintegrates.

The ice conditions on 16-17 November represent the maximum extent of the landfast ice before breakup. Figure 6 shows the fast ice extending from Point Hancock around the whole North Fork. A tongue of ice extends out from Point Brennan and partially encloses the north portion of North Fork. A comparable tongue of ice has begun to grow northward from Northwest Point. However, the center of North Fork remains open except for frazil crystals and grease ice.

The second breakup occurred on 18 November. The ice, which was 2 to 3 inches thick, began to break away from the shore and to move toward the center of the fjord. By 19 November (fig. 7) North Fork was free of ice except for scattered remnants drifting out with the tide and except for the coves east of Point Emmons, which were still frozen. The breakup was caused by a combination of warm temperatures and spring tide. On 18 November a maximum air temperature of 27° F. was recorded which weakened the ice considerably. The high tide then carried it out of North Fork. It is assumed that the ice drifted along the south shore of the fjord into Davis Strait as did the earlier drift ice.

Ice immediately began reforming along the north shore. Formation was accelerated by heavy snowfall on 21 November, which rapidly cooled the surface water layer. Fast ice along the north shore grew beyond the 5-fathom line. On 22 November a moderate gale was recorded at Sondrestrom AFB; maximum intensity of 28 miles per hour occurred at 0305Z. This wind blew from the north-northwest and again cleared the fast ice out of North Fork except in the shallow coves east of Point Emmons. As the temperature fell rapidly to -6° F. at 1830Z on 22 November and a mean of -8.2° F. was recorded on 23 November, scattered remnants of drift ice were caught in Michigan Bay and a heterogeneous ice layer rapidly formed. The ice crust was ½-inch thick on 22 November and reached 2 inches on the next day. This date marks the beginning of permanent ice in Michigan Bay.

The ice continued to grow for the next 4 days. A chart representing the conditions from 23 to 27 November is presented in figure 8. At this stage of growth the tongues from Point Brennan and Northwest Point had joined, and the shallowest water at the head of the fjord was nearly covered with a complex pattern of ice. This fast ice was 5 inches thick. Another tongue of shorefast ice extended partly across the fjord from Point Hancock toward Point Brainard over water that averages 100-fathoms in depth. Thus the cooling effect of the land extended nearly across the fjord.

Another breakup of the shorefast ice occurred on 28 November, driving much of the ice down the fjord and leaving ice only in the shallowest portions of the northern part of the North Fork (fig. 9). This breakup was caused by high air temperatures which reached a maximum of 39° F. on the 27th and 35° F. on the 28th, causing considerable melting of the ice. Cooler weather on 30 November and 1 December left the ice in the condition shown on the chart.

The comparatively warm air temperatures continued until 4 December and the drift ice was completely removed from North Fork (fig. 10). This drift ice again moved down the fjord (fig. 11) and contributed to the ice shown in the middle reaches of the fjord.

The breakup during the first days of December was the last of the winter. Fast ice began to spread again from the shallows on 5 December, when the maximum temperature was 6° F. and the minimum -10° F. By 9 December the fast ice covered the entire North Fork (fig. 12), with the outer periphery extending from Point Hancock to Point Marvin. Thickness of the ice in Michigan Bay was 10 inches on 6 December and 12.5 inches on 9 December.

## B. Formation of Ice in North Fork

The first ice appears in the shallow sheltered areas at the head of North Fork, particularly in Michigan Bay and the small coves east of Point Emmons. After the initial ice formation, shorefast ice grows rapidly until it approaches approximately the 5-fathom line from Point Brennan to Point Emmons and near the mouth of the Watson River. However, the south shore remains relatively ice free since the coastal slope is steeper, and greater depths are reached near shore.

As the fast ice approaches the 10-fathom line, a tongue of ice builds from Point Brennan toward the center of the fjord. Under normal freezing conditions shore ice appears on the south coast a day or so later. A tongue later forms from Northwest Point. This tongue eventually meets with the one projecting from Point Brennan south of the center of North Fork. The final stage of formation is reached when grotesque fingers and tongues of ice extend toward the middle of North Fork from the shorefast ice. Geometrical patterns are formed, as offshoots of ice from these fingers and tongues join together to isolate small open water areas. These water areas then freeze over and the North Fork becomes covered with a sheet of ice.

Other tongues appear farther down the fjord at various peninsulas such as Point Marvin and Point Hancock to accelerate the rapid ice building.

### C. Pressure Ridging in North Fork

On 27 November a pressure ridge was noted in Michigan Bay, parallel to the peninsulas on either side of the bay. The ridge was 1 foot high and 1 yard wide and extended the full length of the bay from the dock to the tips of the peninsulas. This ridging occurred during a period of intense warming, the air temperature being above freezing. It also occurred during the time of neap tide, with the moon in the last quarter.

A possible explanation for this ridging may be that the flood tide or rising water places the greatest pressure at the head of the fjord, as the land mass would act as a barrier. Since the ice was weak due to above freezing temperatures, it would be susceptible to rupture under strain. This theory does not explain why the ice broke parallel to the force rather than normal to it.

Another explanation might be that the sheet of ice covering the bay lowered at neap tide, became suspended on the shore, and cracked under its own weight. Later, when the tide rose again, the ice sheet was floated so as to force the two sections together, thereby forming the ridge.

## IV. DEGREE-DAY FORECASTING IN SØNDRE STRØMFJORD

The Oceanographic Forecasting Central has made extensive use of the degree-day-of-frost concept in ice forecasting.

Degree-days of frost are obtained by subtracting the mean daily air temperature from the freezing temperature of the water. Cumulative degree-days represent the algebraic addition of the degree-days of frost for each successive day. The approximate freezing temperature of the fjord water is 30° F. corresponding to the average salinity encountered. It is customary to abbreviate the term "degree-days of frost" to "degree-days" when making ice forecasts.

In 1953 the first ice formed after 232 degree-days, beginning on 13 October. The first permanent ice was established after 678 degree-days. A list of daily temperatures and degree-day totals is given in table III along with the ice thickness. Figures 13 and 14 show how the ice thickness varied with time and with degree-day accumulation.

Table III - Air temperatures (°F.) and degree-days of frost in Søndre Strømfjord, autumn 1953

| Date | | Max. | Min. | Average | Degree-Days | Total Degree-Days | Total Degree-Days After Permanent Ice Formation | Ice Thickness or Type (Inches) |
|---|---|---|---|---|---|---|---|---|
| Oct. | 13 | - | - | 24.0 | 06.0 | 06.0 | | |
| " | 14 | - | - | 25.0 | 05.0 | 11.0 | | |
| " | 15 | 32 | 13 | 22.5 | 07.5 | 18.5 | | |
| " | 16 | 40 | 15 | 27.5 | 02.5 | 21.0 | | |
| " | 17 | 27 | 15 | 21.0 | 09.0 | 30.0 | | |
| " | 18 | 22 | 12 | 17.0 | 13.0 | 43.0 | | |
| " | 19 | 22 | 13 | 17.5 | 12.5 | 55.5 | | |
| " | 20 | 21 | 16 | 18.5 | 11.5 | 67.0 | | |
| " | 21 | 24 | 16 | 20.0 | 10.0 | 77.0 | | |
| " | 22 | 27 | 13 | 20.0 | 10.0 | 87.0 | | |
| " | 23 | 26 | 19 | 22.5 | 07.5 | 94.5 | | |
| " | 24 | 22 | 05 | 13.5 | 16.5 | 111.0 | | |
| " | 25 | 18 | 02 | 10.0 | 20.0 | 131.0 | | |
| " | 26 | 31 | 15 | 23.0 | 07.0 | 138.0 | | |
| " | 27 | 39 | 23 | 31.0 | -01.0 | 137.0 | | |
| " | 28 | 44 | 25 | 34.5 | -04.5 | 132.5 | | |
| " | 29 | 25 | 11 | 18.0 | 12.0 | 144.5 | | |
| " | 30 | 11 | 05 | 08.0 | 22.0 | 166.5 | | |
| " | 31 | 22 | 11 | 16.5 | 13.5 | 180.0 | | |
| Nov. | 1 | 15 | 09 | 12.0 | 18.0 | 198.0 | | |
| " | 2 | 15 | 10 | 12.5 | 17.5 | 215.5 | | |
| " | 3 | 15 | 11 | 13.0 | 17.0 | 232.5 | | Slush (initial |
| " | 4 | 15 | 08 | 11.5 | 18.5 | 251.0 | | ice formation) |
| " | 5 | 08 | -08 | 00.0 | 30.0 | 281.0 | | |
| " | 6 | 05 | -10 | -02.5 | 32.5 | 313.5 | | |
| " | 7 | 20 | 07 | 13.5 | 16.5 | 330.0 | | 3 |
| " | 8 | 30 | 10 | 20.0 | 10.0 | 340.0 | | |
| " | 9 | 10 | 03 | 06.5 | 23.5 | 363.5 | | None |
| " | 10 | 11 | -05 | 03.0 | 27.0 | 390.5 | | Thin |
| " | 11 | 04 | -05 | -00.5 | 30.5 | 421.0 | | Grease |
| " | 12 | 00 | -10 | -05.0 | 35.0 | 456.0 | | 3/4 |
| " | 13 | -08 | -13 | -10.5 | 40.5 | 496.5 | | |
| " | 14 | 08 | -09 | -00.5 | 30.5 | 527.0 | | Slush |
| " | 15 | 06 | -07 | -00.5 | 30.5 | 557.5 | | |
| " | 16 | 03 | -02 | -00.5 | 29.5 | 587.0 | | 2 |
| " | 17 | 08 | 03 | -06.5 | 23.5 | 610.5 | | None |
| " | 18 | 27 | 07 | 17.0 | 13.0 | 623.5 | | |
| " | 19 | 18 | 06 | 12.0 | 18.0 | 641.5 | | |
| " | 20 | 14 | 07 | 10.5 | 19.5 | 661.0 | | Slush |
| " | 21 | 21 | 05 | 13.0 | 17.0 | 678.0 | | None |
| " | 22 | 18 | -06 | 06.0 | 24.0 | 702.0 | 24.0 | ¼ (First perman- |
| " | 23 | -03 | -14 | -08.5 | 38.5 | 740.5 | 62.5 | 2 ent ice) |

Table III - Air temperatures ($^{o}$F.) and degree-days of frost in Søndre Strømfjord, autumn 1953

| Date | Max. | Min. | Average | Degree-Days | Total Degree-Days | Total Degree-Days After Permanent Ice Formation | Ice Thickness or Type (inches) |
|---|---|---|---|---|---|---|---|
| Nov. 24 | -01 | -11 | -06.0 | 36.0 | 776.5 | 98.5 | |
| " 25 | 06 | -12 | -03.0 | 33.0 | 809.5 | 131.5 | |
| " 26 | 14 | 04 | 09.0 | 21.0 | 830.5 | 152.5 | 5 |
| " 27 | 39 | 13 | 26.0 | 04.0 | 834.5 | 156.5 | |
| " 28 | 35 | 22 | 28.5 | 01.5 | 836.0 | 158.0 | |
| " 29 | 24 | 15 | 19.5 | 10.5 | 846.5 | 168.5 | |
| " 30 | 15 | -03 | 06.0 | 24.0 | 870.5 | 192.5 | |
| Dec. 1 | 20 | -05 | 07.5 | 22.5 | 893.0 | 215.0 | 8 |
| " 2 | 20 | 09 | 14.5 | 15.5 | 908.5 | 230.5 | |
| " 3 | 34 | 21 | 27.5 | 02.5 | 911.0 | 233.5 | |
| " 4 | 18 | 03 | 10.5 | 19.5 | 930.5 | 252.5 | |
| " 5 | 06 | -10 | -02.0 | 32.0 | 962.5 | 284.5 | |
| " 6 | 05 | -05 | 00.0 | 30.0 | 992.5 | 314.5 | 10 |
| " 7 | 03 | -11 | -04.0 | 34.0 | 1026.5 | 348.5 | |
| " 8 | -02 | -16 | -09.0 | 39.0 | 1065.5 | 387.5 | |
| " 9 | -08 | -16 | -12.0 | 42.0 | 1107.5 | 429.5 | |
| " 10 | -14 | -19 | -16.5 | 46.5 | 1154.0 | 476.0 | |
| " 11 | -13 | -19 | -16.0 | 46.0 | 1200.0 | 522.0 | |
| " 12 | -13 | -17 | -15.0 | 45.0 | 1245.0 | 567.0 | |

Ice thickness measurements and growth data are available for the 1949-50 ice season. In figure 15 the ice thicknesses at comparable dates in 1949 and 1953 are shown. It is seen that ice formed earlier in 1949 and accumulated to greater thicknesses at comparable dates than in 1953. By the use of extrapolation and the accumulation of degree-days it is determined that the 1953 freezing season began with a lower than normal rate of degree-day accumulation. The rate of accumulation remained below normal until approximately 27 October when the trend reversed and the rate became above normal. In other words, freezing occurred later than usual in 1953. However, as the autumn progressed, temperatures fell below the 10-year average and the ice grew faster than normal. In 1949 the ice was 4 inches thick on 28 October, while initial ice did not form in 1953 until 3 November. The first 7 days in December 1949 were much below freezing (ranging from -4° to 9° F.), so that the curves for 1949 and 1953 are more or less parallel for the period under study. Temperature means for previous years, an average year, and 1953 are given in figure 16. Both the temperature comparison and the ice growth data for 1953 support the long-range forecast of the Oceanographic Forecasting Central that 1954 would be a more severe ice year than 1953 in the Davis Strait area.

## V. SUMMARY

The oceanographic and meteorological conditions at Søndre Strømfjord were studied to find the relationship between these conditions and the growth of ice in the fjord. The sequence of ice growth during the autumn of 1953 was described in detail, and by comparison with other seasons, a normal history of ice growth was presented. The use of the degree-day of frost concept in ice growth forecasting was described, and the season of 1953-54 was evaluated in the light of knowledge of temperatures in previous seasons. Ice formed in 1953 later than in 1949, but a faster accumulation of degree-days in 1953 produced comparable growth in the two seasons.

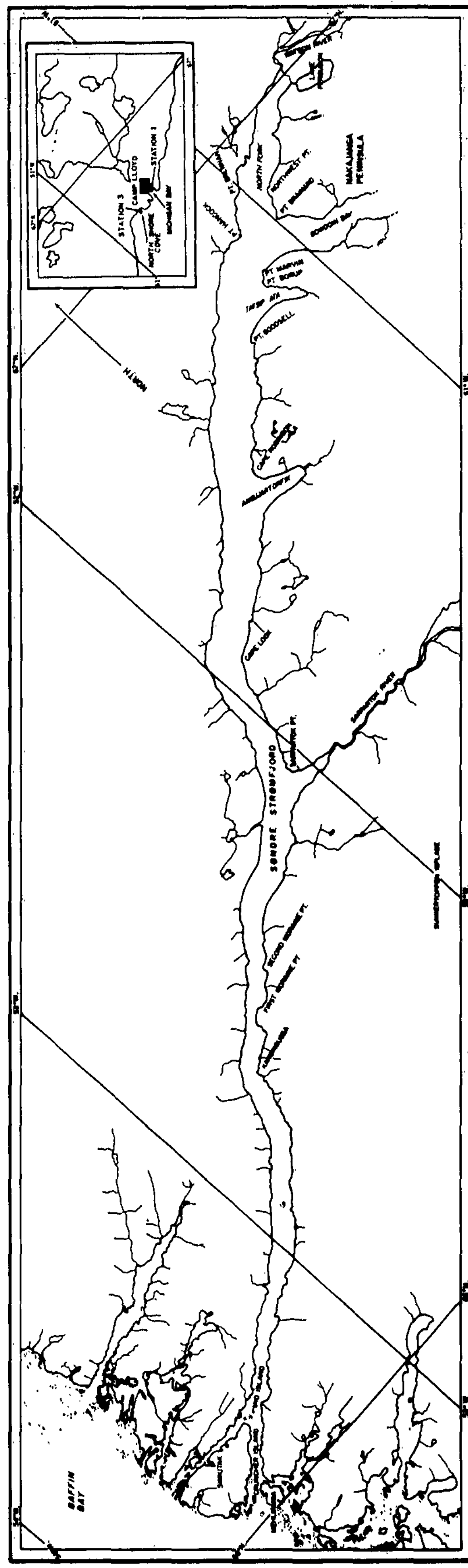


FIGURE 1. LOCATION CHART - SØNDRE STRØMFJORD

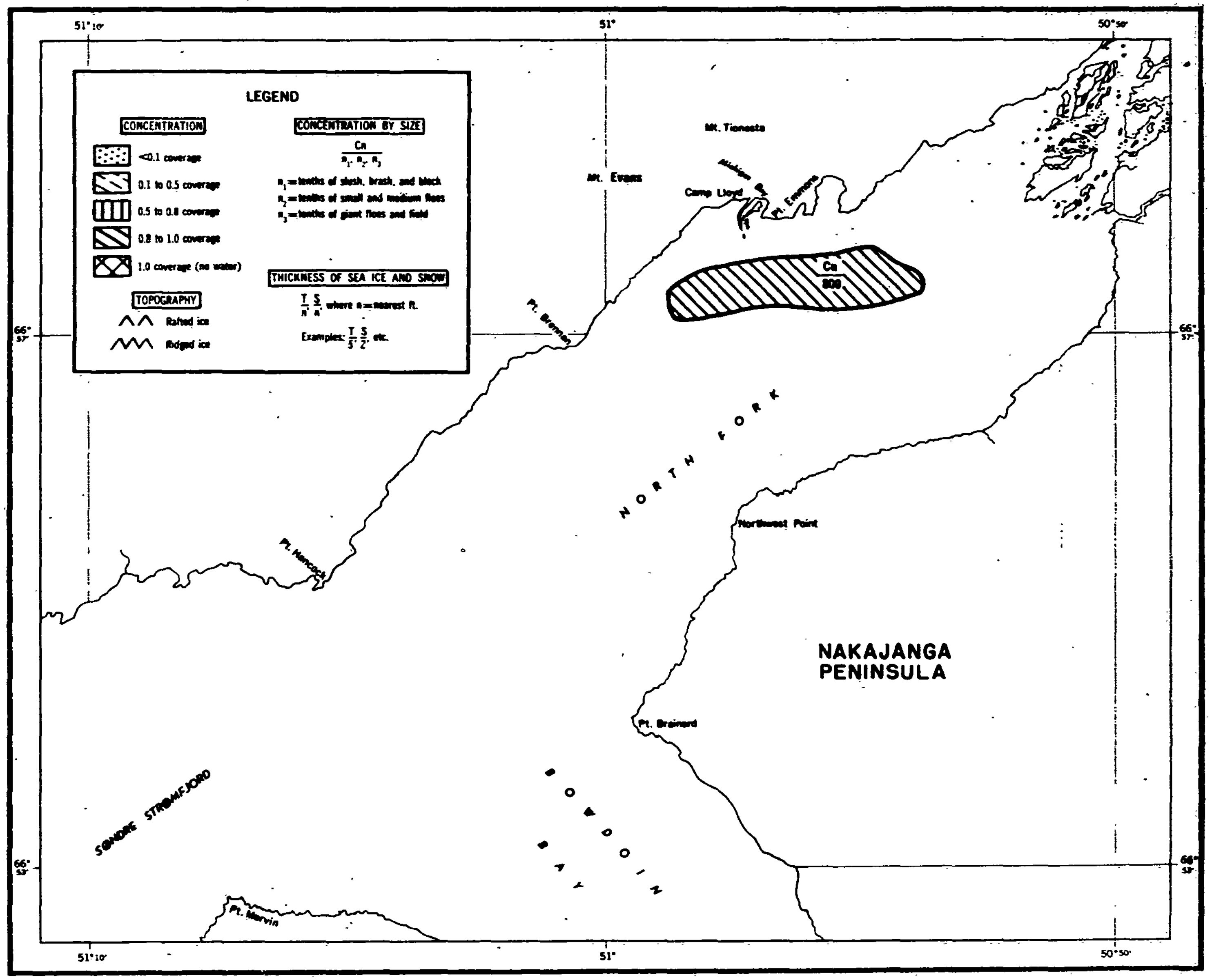


FIGURE 2. ICE CHART FOR 7 NOVEMBER 1953 (INITIAL OBSERVATION)

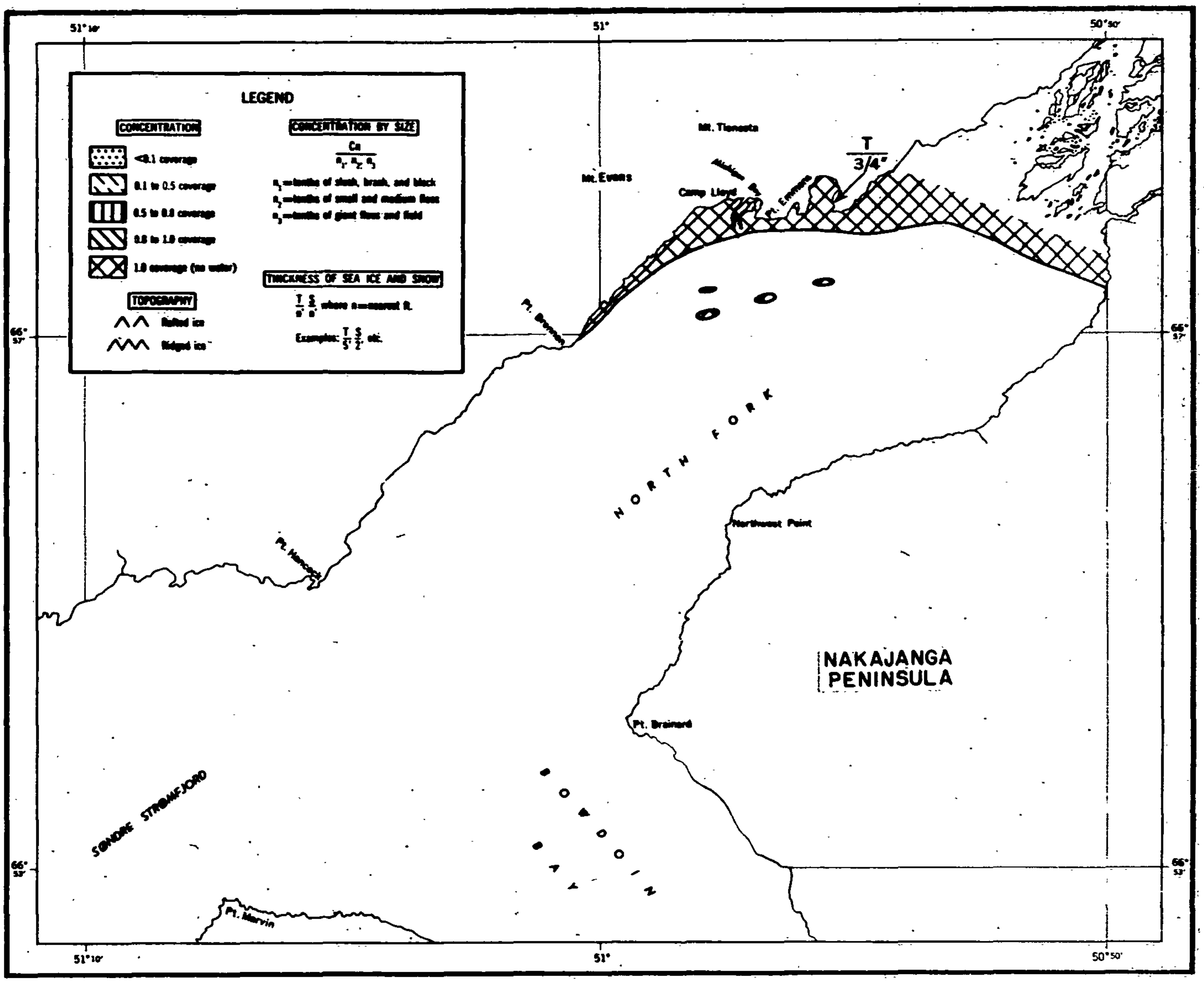


FIGURE 3. ICE CHART FOR 10-12 NOVEMBER 1953

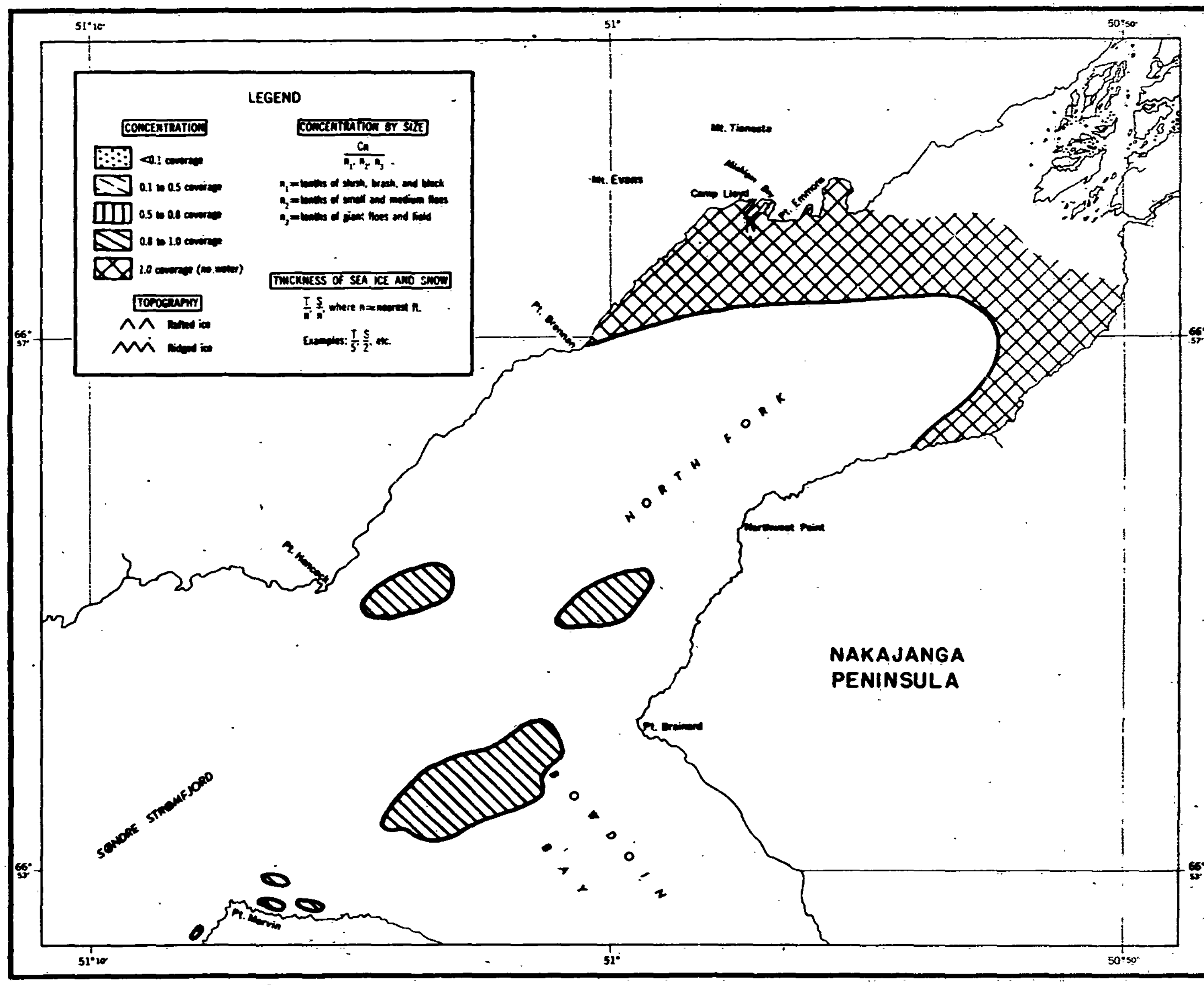


FIGURE 4. ICE CHART FOR 13—15 NOVEMBER 1953

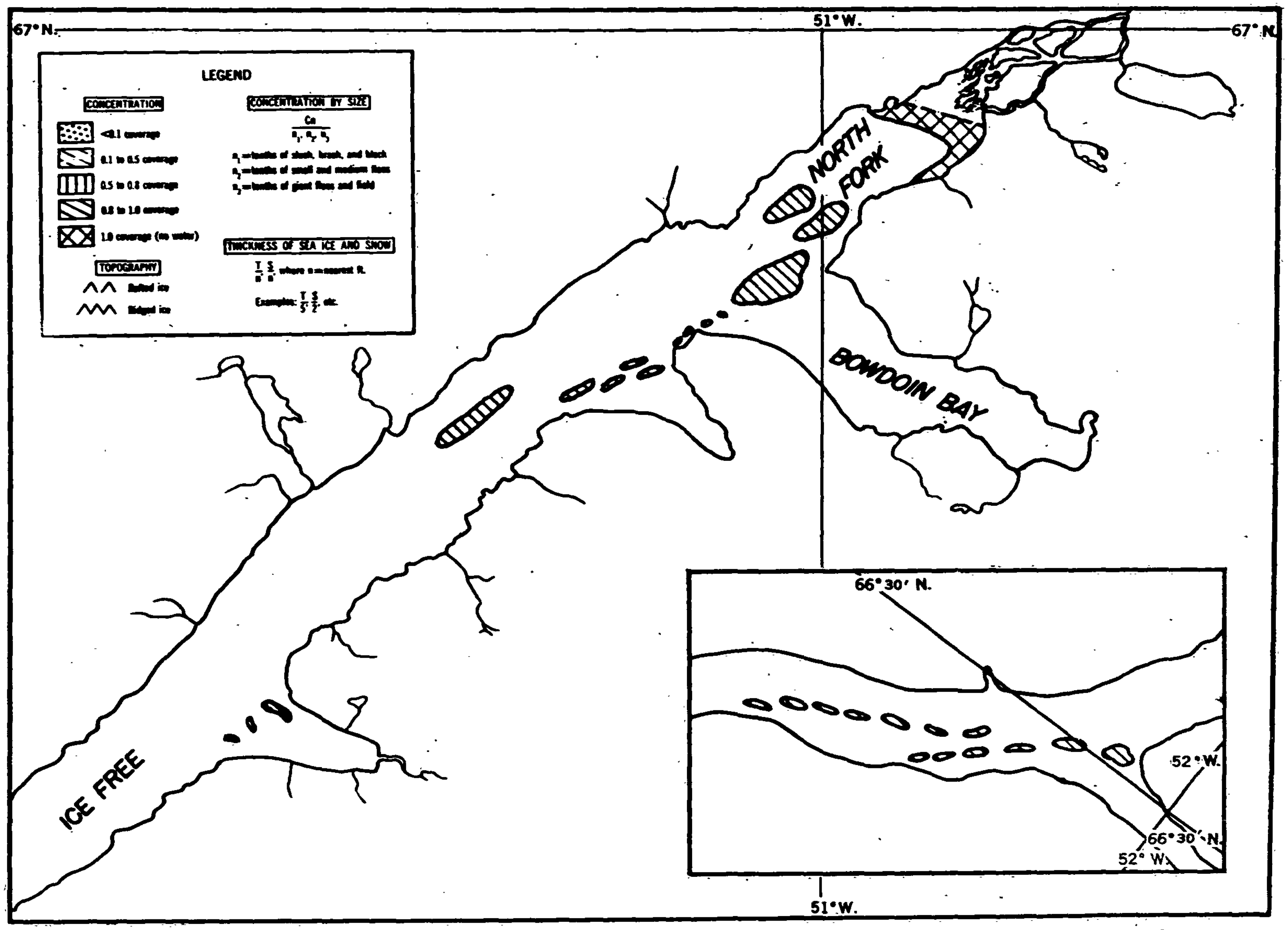


FIG. 5. ICE CHART FOR 14 NOVEMBER 1953, SHOWING ALL THE ICE IN SØNDRE STRØMFJORD

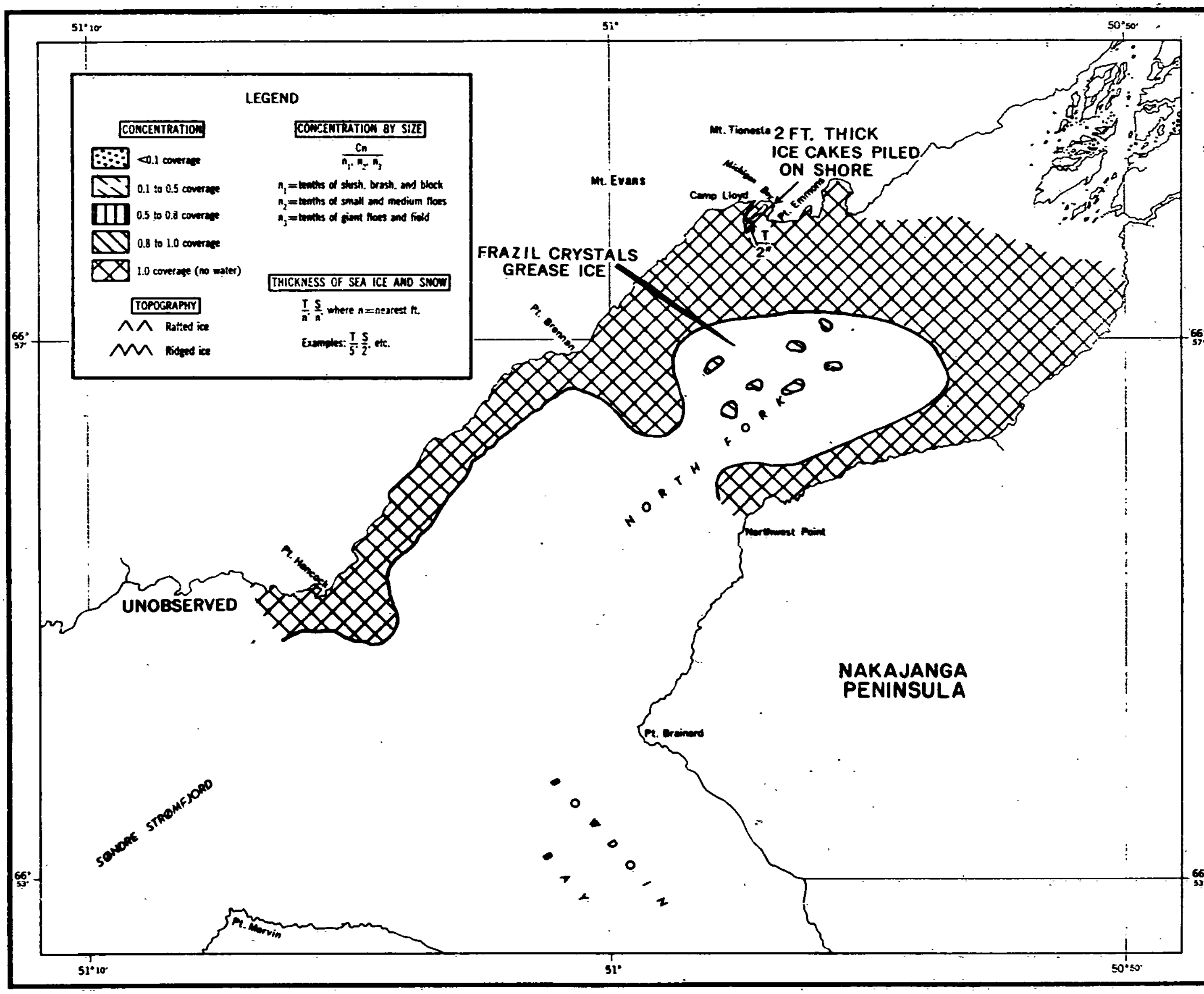


FIGURE 6. ICE CHART FOR 16-17 NOVEMBER 1953

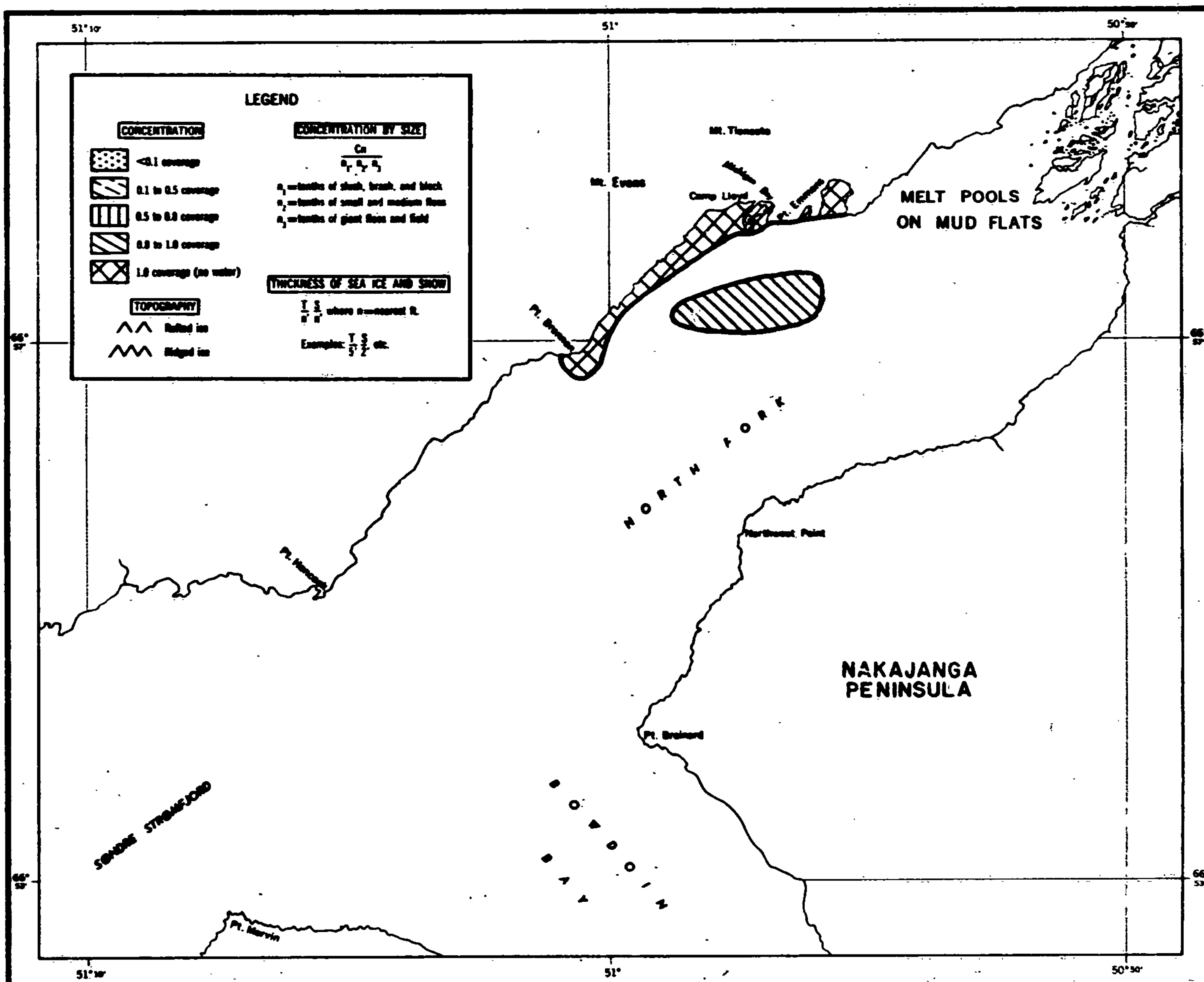


FIGURE 7. ICE CHART FOR 19 NOVEMBER 1953

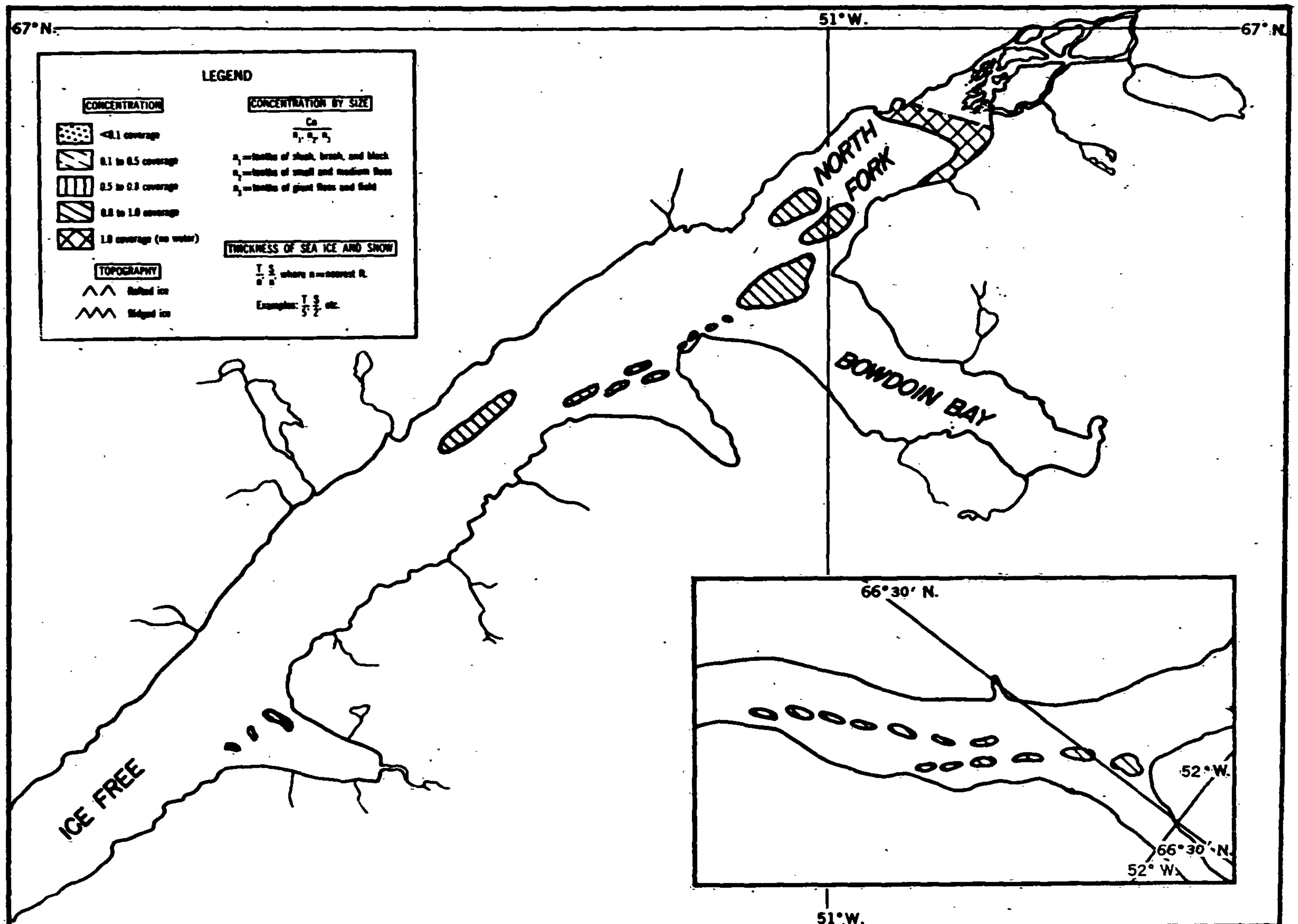


FIG. 5. ICE CHART FOR 14 NOVEMBER 1953, SHOWING ALL THE ICE IN SØNDRE STRØMFJORD

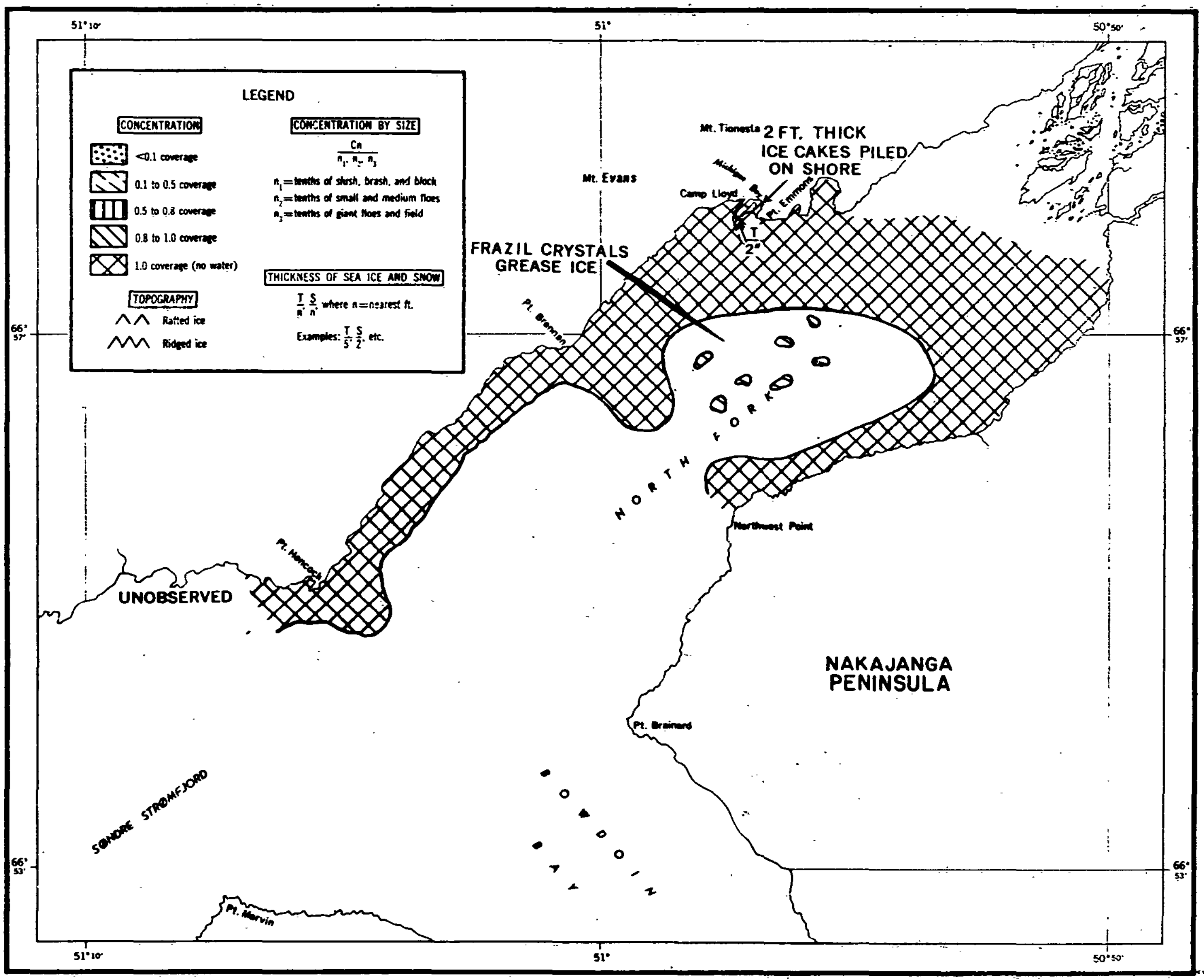


FIGURE 6. ICE CHART FOR 16-17 NOVEMBER 1953

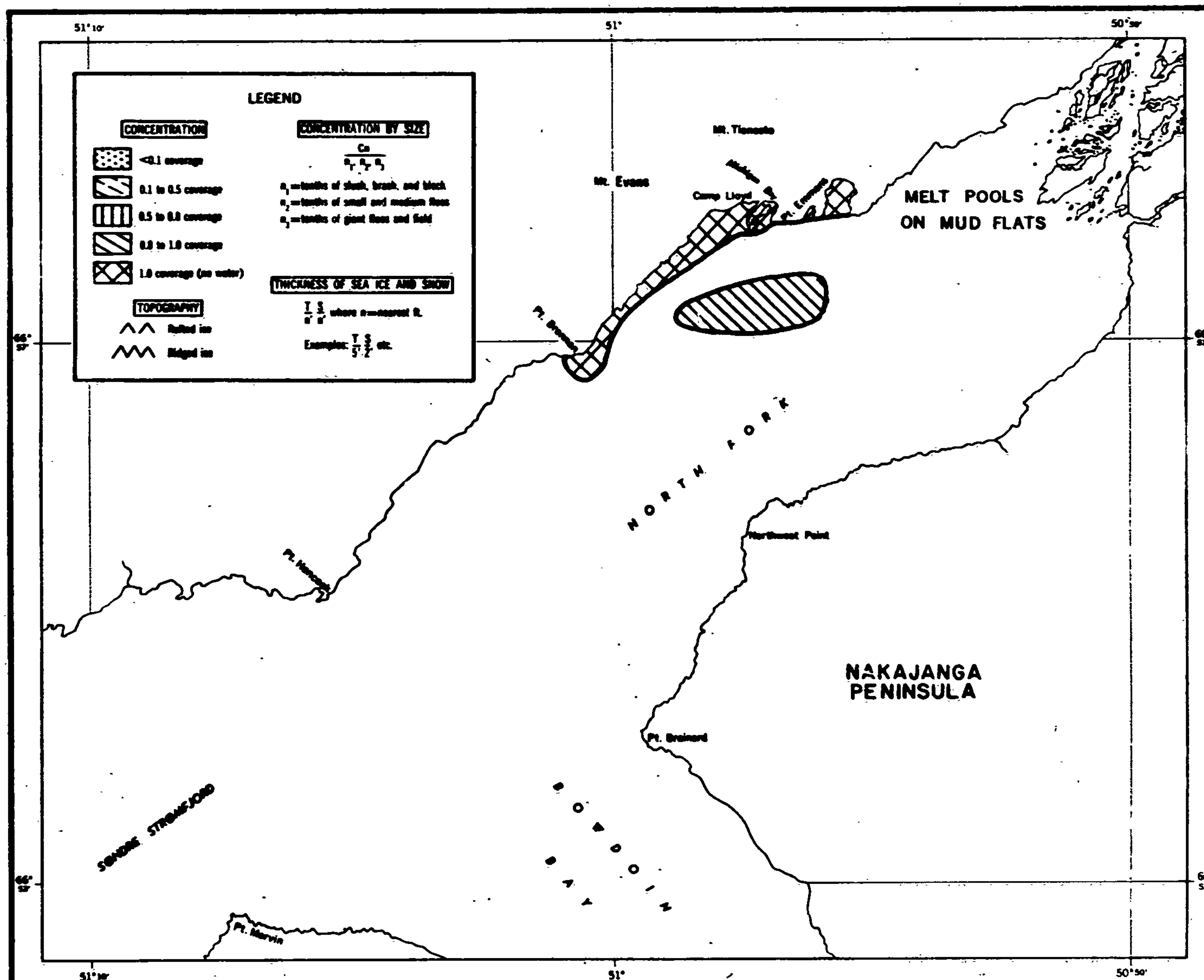


FIGURE 7. ICE CHART FOR 19 NOVEMBER 1953

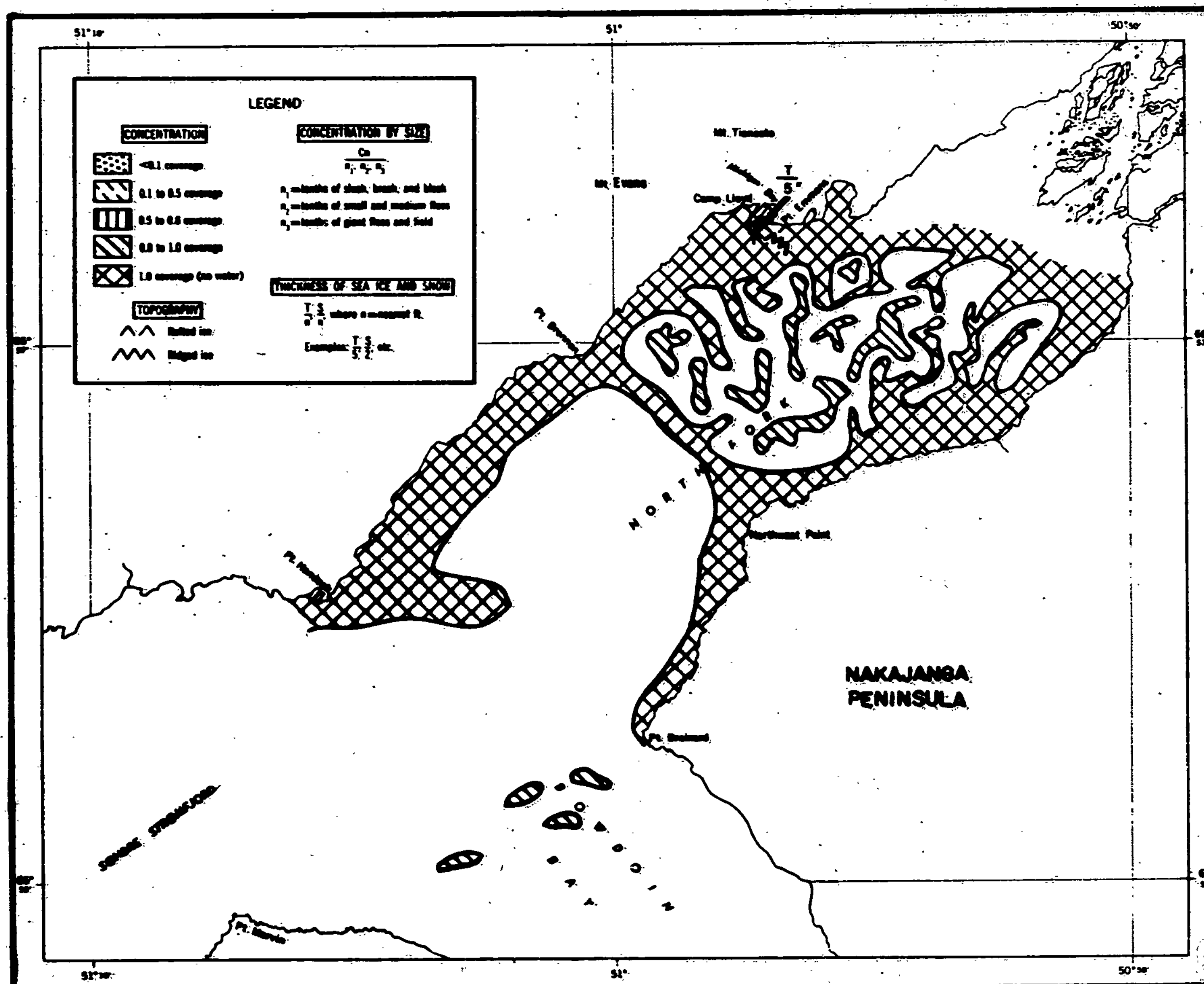


FIGURE 8. ICE CHART FOR 23-27 NOVEMBER 1953

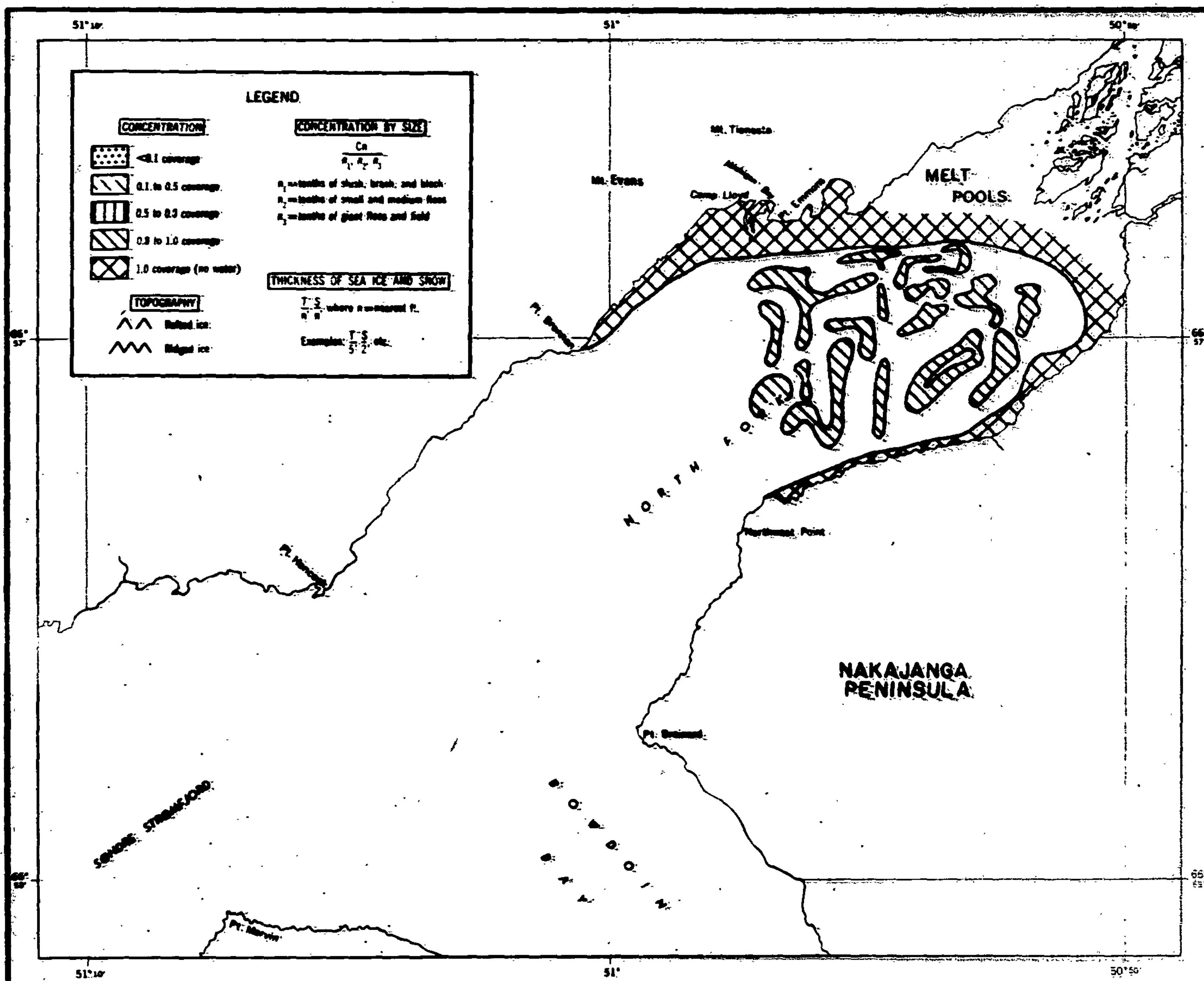


FIGURE 9. ICE CHART FOR 28 NOVEMBER TO 1 DECEMBER 1953

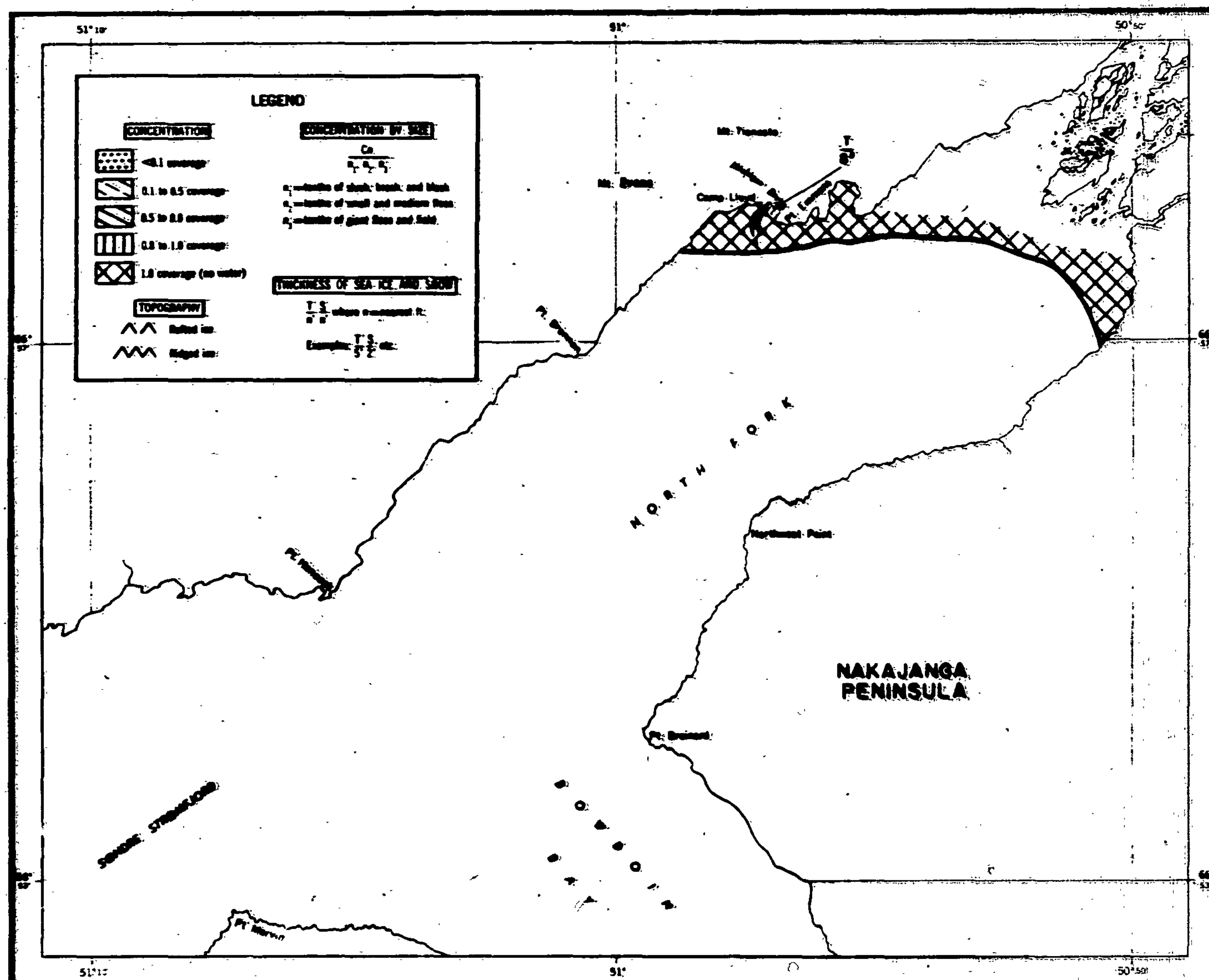


FIGURE 10. ICE CHART FOR 2–4 DECEMBER 1953

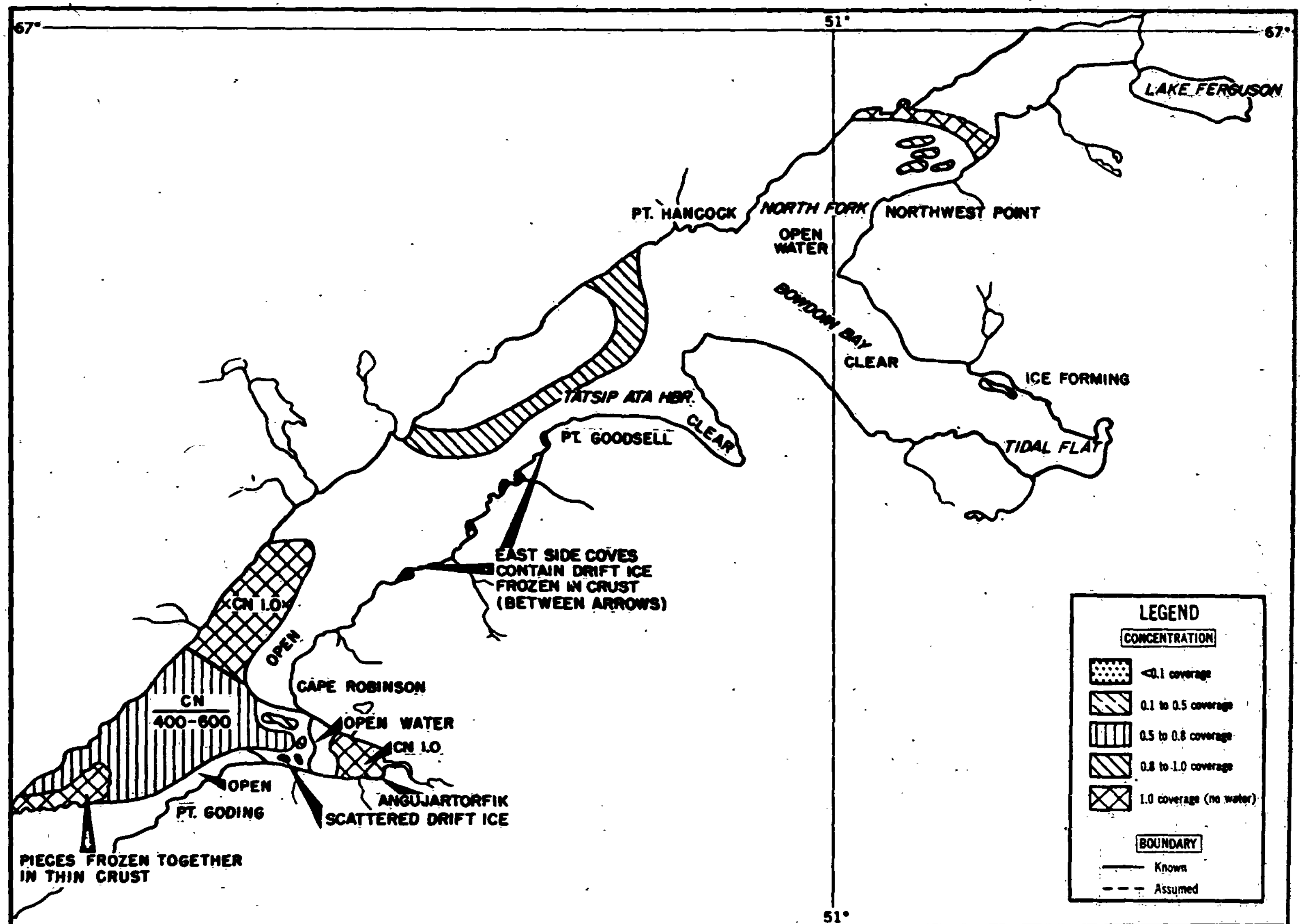


FIGURE 11. ICE CHART FOR 4 DECEMBER 1953

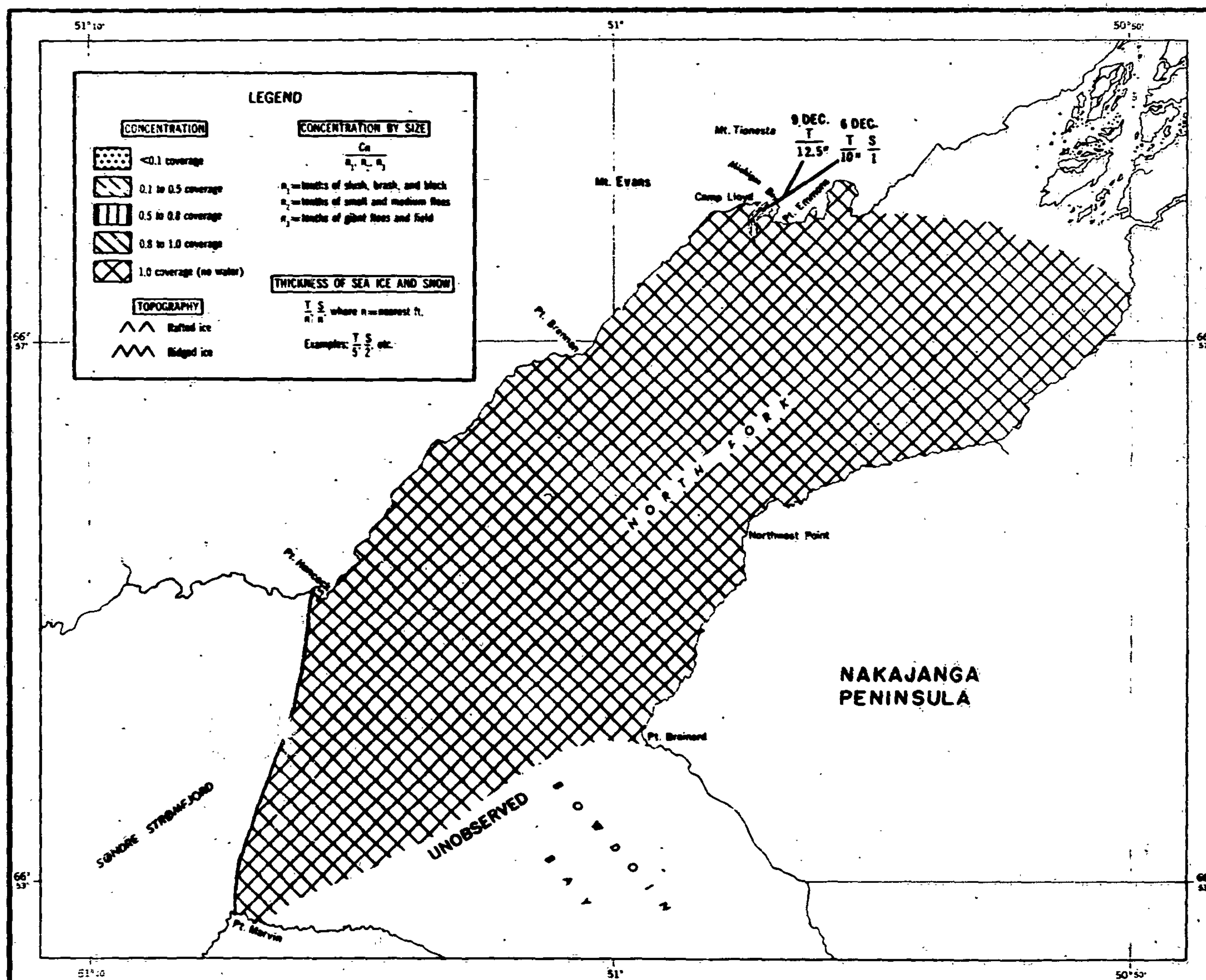


FIGURE 12. ICE CHART FOR 6–9 DECEMBER 1953 (FINAL OBSERVATION)

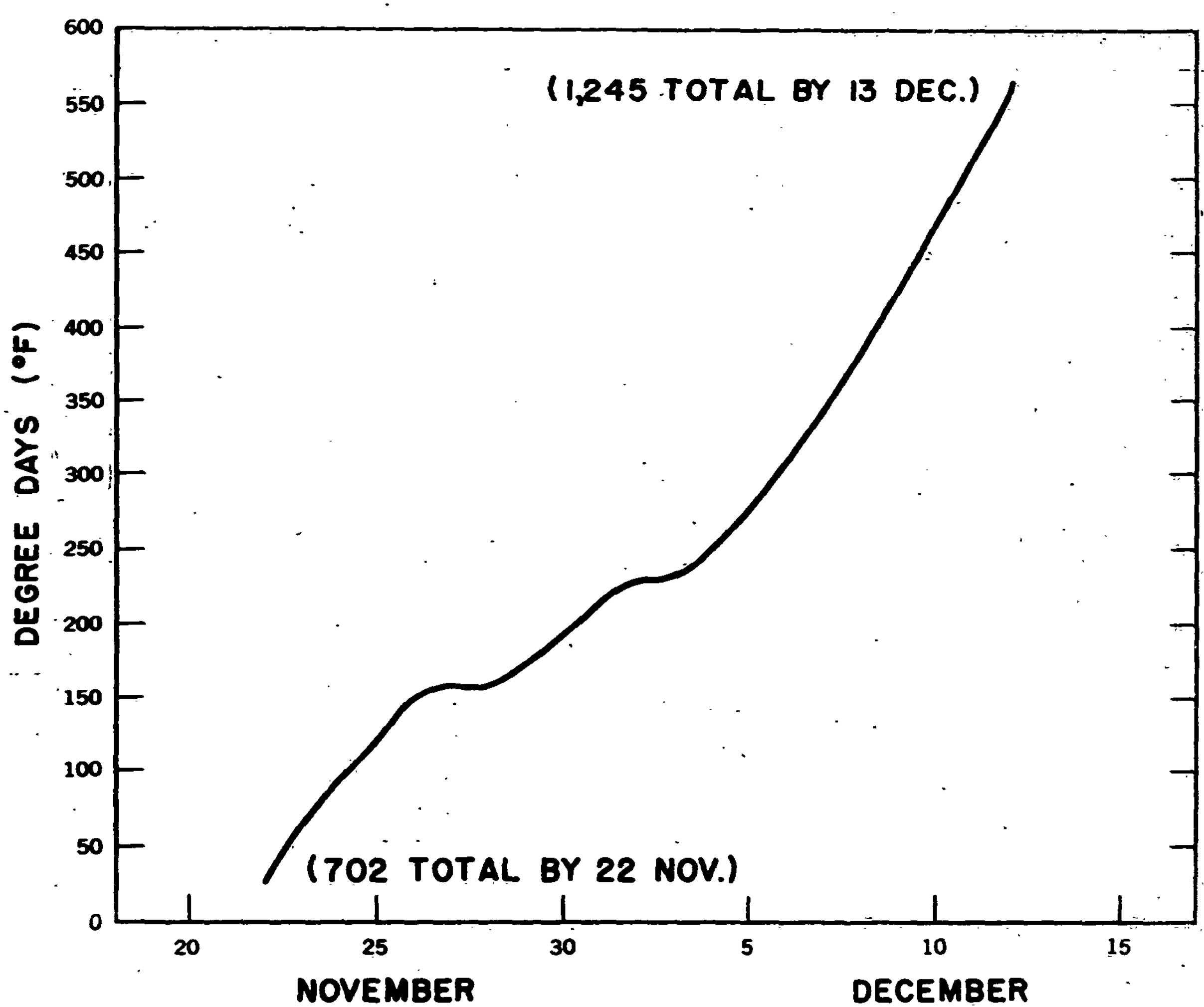


FIGURE 13. DEGREE-DAY ACCUMULATION AFTER FIRST PERMANENT ICE FORMATION, 1953

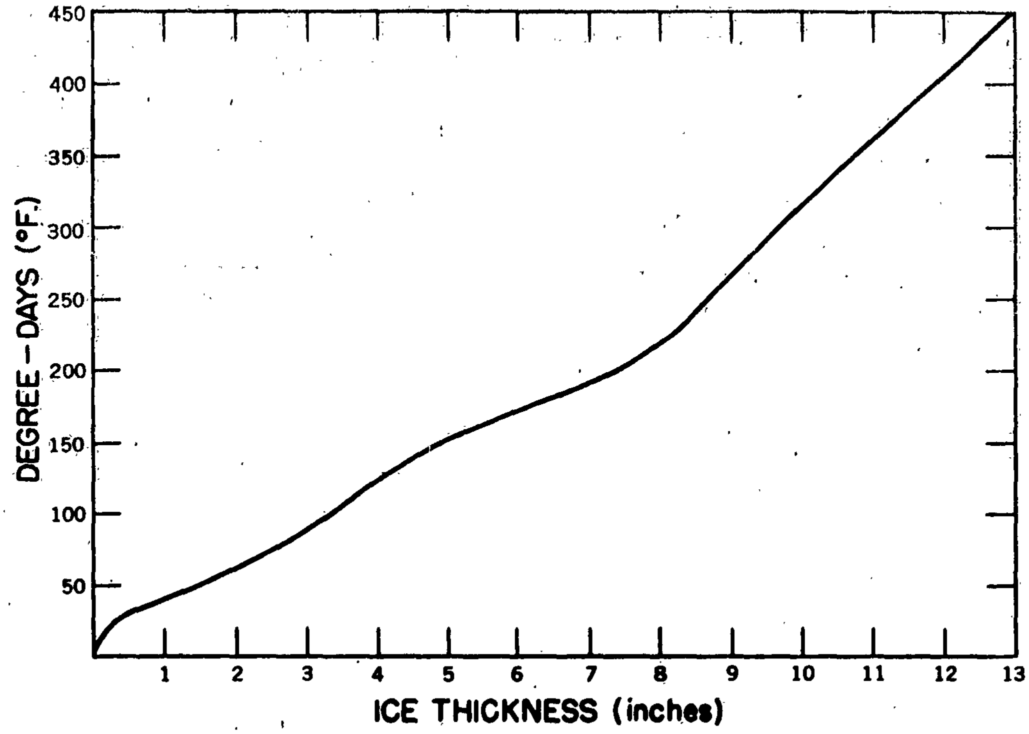


FIGURE 14. ICE GROWTH WITH RESPECT TO DEGREE-DAY ACCUMULATION FOR THE EARLY PART OF THE 1953-54 SEASON.

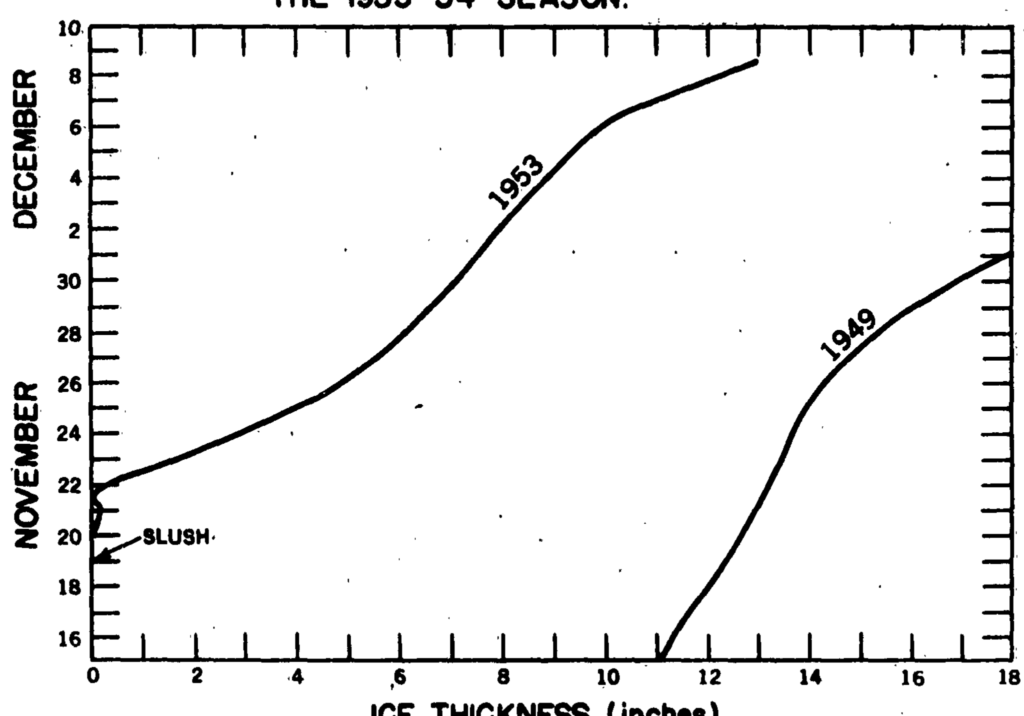


FIGURE 15. ICE GROWTH FOR THE EARLY PART OF THE 1949-50 AND 1953-54 SEASONS.

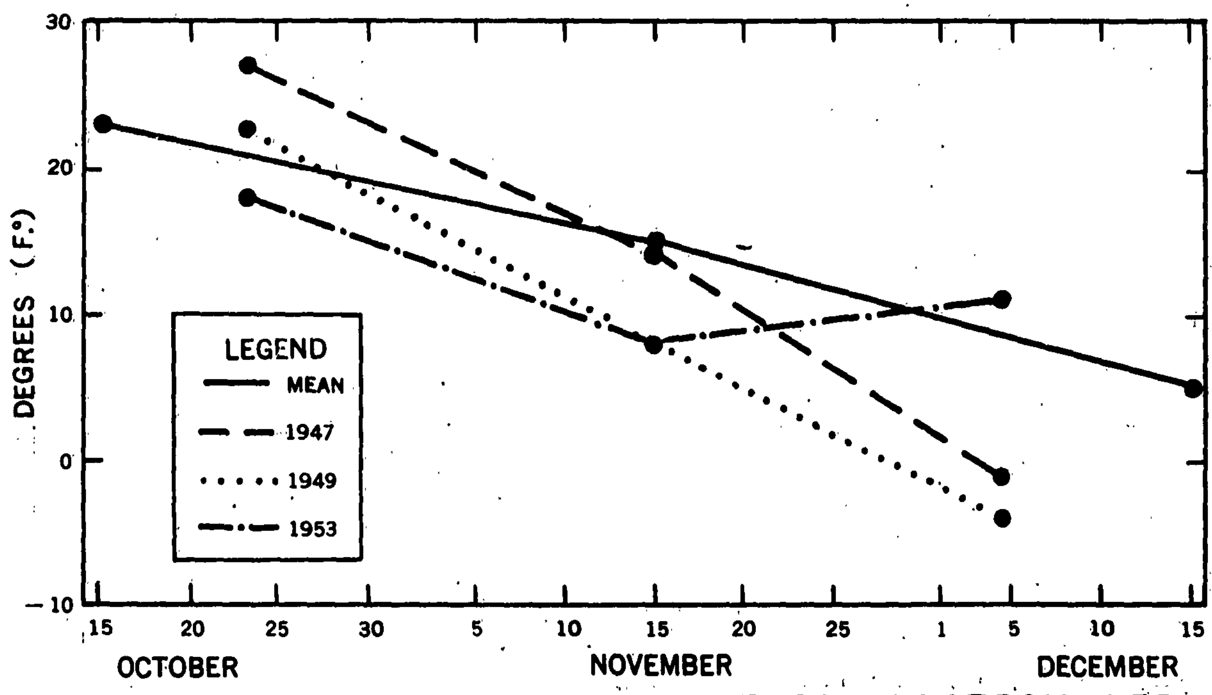


FIGURE 16. AIR TEMPERATURE AT SONDRESTROM AFB

# BIBLIOGRAPHY


BOORKE, A. K. [BURKE, A. K.?]. Sea ice [Morskie L'dy]. (Translated into Russian by Eugenie Olkhine, 1940). Leningrad and Moscow: Glavsevmor-put. [Translated into English by Bessit Weissman, 1947]. Unpublished. 116 p.

LEE, O. S., and SIMPSON, L. S. A practical method of predicting sea ice formation and growth. U. S. Hydrographic Office Technical Report 4. Washington: 27 p. 1954.

SVERDRUP, H. U., JOHNSON, M. W., and FLEMING, R. H. The oceans; their physics, chemistry and general biology. New York: Prentice-Hall. 1087 p. 1942.

U. S. AIR FORCE, 8th WEATHER SQUADRON. Climate of the Northeast Air Command region. Technical Memorandum No. 6, 4 p., 60 figs. 1953.

U. S. AIR WEATHER SERVICE. Northern hemisphere historical weather maps. October-December, 1945-1948.

U. S. COAST AND GEODETIC SURVEY. Tide tables east coast North and South America (including Greenland) for the year 1953, Serial No. 753. Washington: 249 p. 1951.

U. S. HYDROGRAPHIC OFFICE. A functional glossary of ice terminology. Hydrographic Office Publication No. 609. Washington: 88 p. 1952.

- - - Long range ice outlook and tide predictions for SUNEC 1954. Hydrographic Office Misc. 15869-1A. Washington: 80 p. 1954.

U. S. WEATHER BUREAU. Daily series synoptic weather maps. January-December 1949, October-December 1950, and October-December 1951.

- - - NATIONAL WEATHER RECORDS CENTER. Flying weather wind roses for Sondrestrom AFB, Greenland (16504). Prepared for U. S. Air Weather Service, Data Control Division. [various paging]. Unpublished.

- - - Uniform summary of surface weather observations for Sondrestrom AFB, Greenland (16504); Part A - Derived from Hourly Observations. Part B - Derived from Daily Observations. Prepared for U. S. Air Weather Service, Data Control Division. [n. p.]. Unpublished.

U. S. Navy Hydrographic Office
LOCAL ENVIRONMENTAL FACTORS AFFECTING ICE FORMATION IN SØNDRE STRØMFJORD, GREENLAND, by James R. D. Tapager, November 1955. 10 p. 16 figures, 3 tables. (H. O. TR-22)

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2. Søndre Strømfjord - Sea Ice
3. Oceanography
4. Meteorology

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